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TITLE: EXPERIMENTAL PROCEDURE FOR PERMEABILITY TESTING OF BENTONITE SEALS

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EXPERIMENTAL PROCEDURE FOR PERMEABILITY TESTING OF BENTONITE SEALS

1. Objective

The objective of this procedure is to determine the coefficient of permeability for bentonite seals. The procedure includes two methods: standard falling head, and double-pipette falling head tests.

2. Quality Assurance

All testing activities will comply with the SNL WIPP quality assurance program, and will be documented in scientific notebooks and on test report form (Appendix). Results of testing as documented in notebook shall be reviewed by the UNR PI or designee (Dated and initialed).

3. Records

All documentation of the testing activities and recording of the results should be identified as QA records and submitted to the principal investigator.

4. Apparatus

1. Permeameters (PVC or stainless steel)
2. Precision pipettes and caps
3. Inflow and outflow tubing (stainless steel or rigid plastic)
4. Precision tape
5. Stop clock
6. Pressure gage
7. Helium gas supplier
8. Vacuum pump
9. Graduated cylinder

5. Testing Procedure

5.1 Sample preparation

Sample preparation and installation shall follow the procedures described in "Sample Preparation and Installation Procedure for Permeability and Swelling Pressure Testing of Bentonite Seals (WIPP Procedure 546)." The chemical components and density of the brine should be analyzed by a chemical analytical laboratory. When the density measurement is not available from the chemical analytical laboratory, the density of the brine will be measured by filling brine into a graduated cylinder and weighed by an electronic balance (0.01 g readability) at 20 and 25°C.

5.2 Sample Saturation

If needed, use a vacuum pump to evacuate the specimen under 50 cm (20 in.) Hg minimum for 15 minutes to remove air adhering to bentonite particles and from the voids. Follow the evacuation by a slow saturation of the specimen from the bottom upward under full vacuum in order to free any remaining air in the specimen. Continued saturation of the specimen can be maintained by the pressurized WIPP brine.

5.3 Standard falling head method (Fig. 1)

(a) Measure and record the inside diameter and calculate the cross-sectional area of the pipette (a, cm^2), and permeameter (A, cm^2) and sample length (L, cm).

(b) Measure the length of the entire graduation. Calibrate and calculate the length per unit volume (l, cm^{-2}). Record the total volume of the graduation of the pipette (V_t, cm^3).

(c) Connect the necessary tubing and pipette according to Fig. 1. Especially when low pressure tubing is used between the pipette and the permeameter, keep the length of tubing to a minimum. This will minimize the effect of volume changes due to the decrease of tubing diameter as the hydrostatic pressure decreases.

(d) Measure the height between the level of outflow and the level of the lowest graduate mark on the pipette. This will be the reference height (H, cm).

(e) Fill the pipette with the WIPP brine and let the brine level drop.

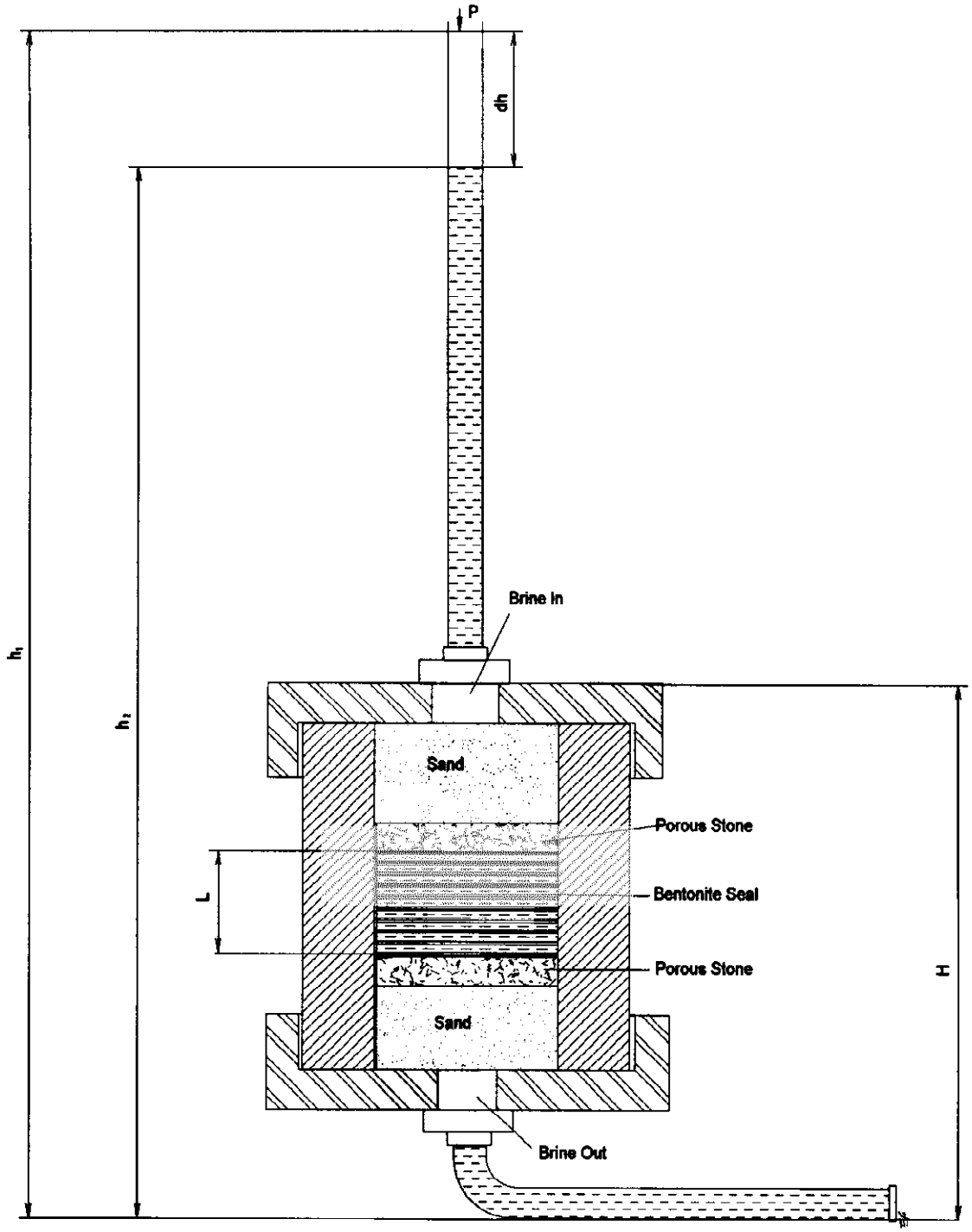

Figure 1 Schematic of flow test setup: standard falling head method.

Note: deaired distilled water will be used for reference tests.

(f) When the brine level drops within the graduation, record the time (t_1) and the graduation reading (V_1). Calculate h_1, using the equation:

$$h_1 = \frac{P_1}{\rho g} + H + l\left(V_t - V_1\right) \qquad (1)$$

where P_1 is the applied pressure at time t_1, ρ is the density of the brine, and g is the specific gravity.

(g) At the time t_2 record the graduation reading (V_2) - Calculate h_2 from:

$$h_2 = \frac{P_2}{\rho g} + H + l\left(V_t - V_2\right) \qquad (2)$$

where P_2 is the applied pressure at time t_2, ρ is the density of the brine, and g is the specific gravity.

(h) The coefficient of permeability K can be computed from:

$$K = \frac{aL}{A\left(t_2 - t_1\right)} \ln \frac{h_1}{h_2} \qquad (3)$$

in which K - coefficient of permeability (cm/s)
a - cross-sectional area of the pipette (cm^2)
A - cross-sectional area of the permeameter (cm^2)
L - sample length (cm)
t_1 - time when water in the pipette is at h_1
t_2 - time when water in the pipette is at h_2
h_1 - height of water level at t_1
h_2 - height of water level at t_2
t_2-t_1 - duration of the permeability measurement(s).

(i) The outflow may be allowed to drain vertically under gravity fall without using the outlet reservoir. The reference height (H) should then be measured from the lowest graduate mark to the bottom of the sample. It is advisable to cover the open end of the pipette to minimize evaporation.

Permeability test data sheet in appendix will be used to record applied pressure, pressure heads, temperature, and sample parameters for permeability calculation.

5.4 Double-pipette falling head method (Fig. 2)

(a) Measure and record the inside diameter of the pipettes and of the permeameter, and the sample length (L). Calculate the cross-sectional area of the pipettes (a, cm^2) and permeameter (A, cm^2). Make sure that the inflow pipette and the outflow pipette are of the same diameter and graduated length.

(b) Measure the length of the pipette graduation (L_p). Record the total graduation volume (V_t, cc). Calibrate and calculate the length per unit volume (l, cm^{-2}), i.e. L_P/V_t.

(c) Connect tubing and pipettes. Keep the tubing length as short as possible.

(d) Measure the height between the lowest graduation mark of the outflow pipette and that of the inflow pipette. This will be the reference height (H, cm).

(e) Record the time t_1, and read the water level in terms of the graduation marks for the inflow pipette (V_{in}) and the outflow pipette (V_{out}).

(f) Calculate h_1 as follows:

$$h_1 = \frac{P_1}{\rho g} + H + l\left(V_{out} - V_{in}\right) \qquad (4)$$

where P_1 is the applied pressure at time t_1, ρ is the density of the brine, g is the specific gravity, V_{out} and V_{in} are the readings measured at time t_1.

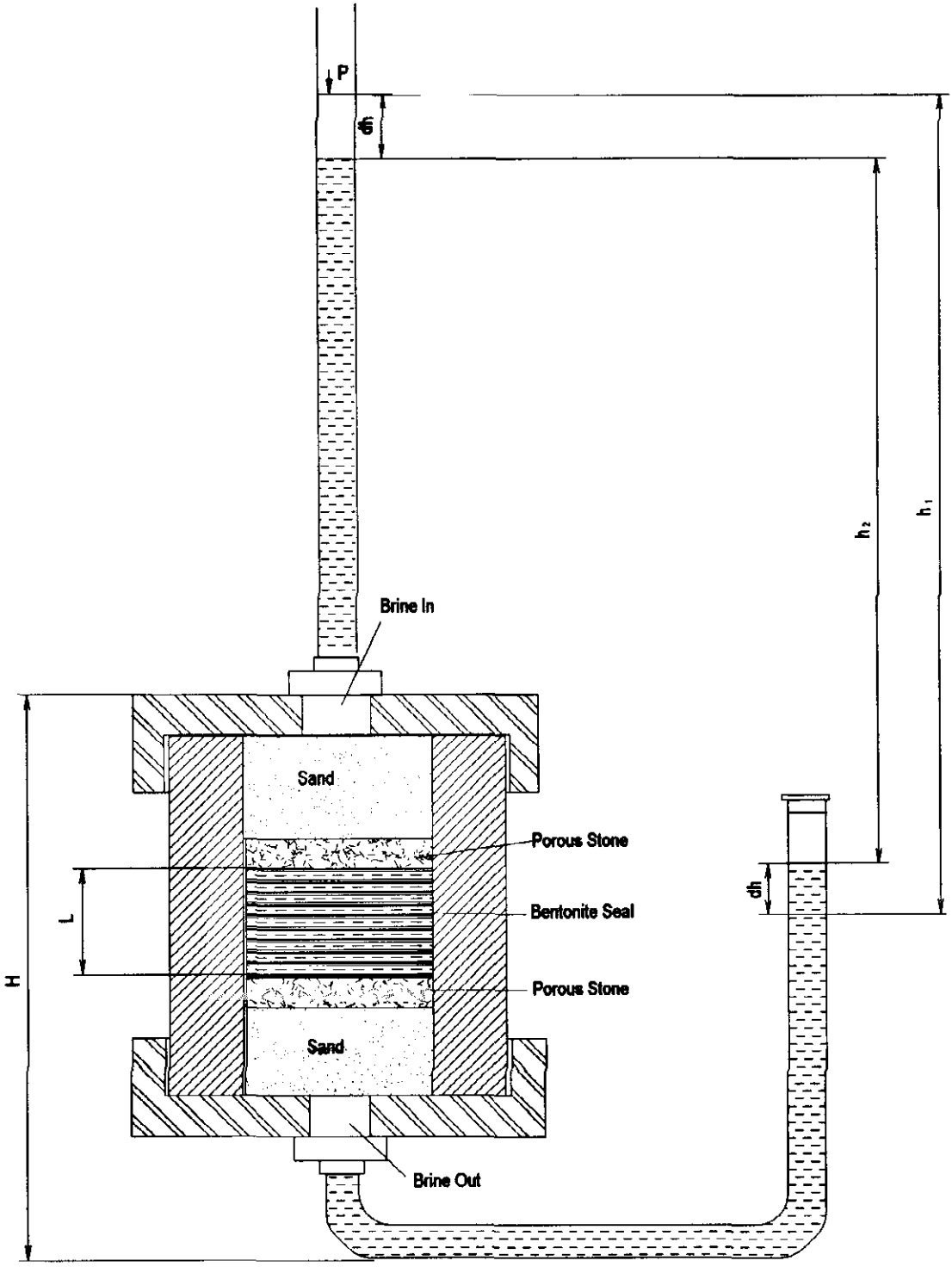

Figure 2 Schematic of flow test setup: double-pipette falling head method.

(g) Record the time t_2. and read the brine levels in both pipettes as described in step (e)

(h) Calculate h_2 using Equation (5).

$$h_2 = \frac{P_2}{\rho g} + H + l\left(V_{out} - V_{in}\right) \qquad (5)$$

where P_2 is the applied pressure at time t_2, ρ is the density of the brine, g is the specific gravity, V_{out} and V_{in} are the readings measured at time t_2.

(I) Calculate the coefficient of permeability K:

$$K = \frac{aL}{2A\left(t_2 - t_1\right)} \ln \frac{h_1}{h_2} \qquad (6)$$

where
- K - coefficient of permeability (cm/s)
- a - cross-sectional area of the pipette (cm^2)
- A - cross-sectional area of the permeameter (cm^2)
- L - sample length (cm)
- t_1 - time when water in the pipette is at h_1
- t_2 - time when water in the pipette is at h_2
- h_1 - height of water level at t_1
- h_2 - heave-ht of water level at t_2.

Permeability test data sheet in appendix will be used to record applied pressure, pressure heads, temperature, and sample parameters for permeability calculation.

6. Report

Run the PERMCAL program with the data recorded in the permeability test data sheets to calculate the permeability of the bentonite seal. Tabulate and plot permeability versus hydraulic gradient, testing time, sample diameter, sample density, brine concentration, the original sample moisture content at compaction, and other parameters which the research is interested in.

7. Calibration

The pressure gage used to measure the applied pressure will have a valid calibration. Use graduated cylinders to calibrate volume as a function of length of pipettes.

8. References

ASTM D 2434 - 68. Standard Test Meshed for Permeability of Granular Soils (Constant Head). *Annual Book of ASTM Standards*, Construction, Vol. 04.08, American Society for Testing and Materials, Philadelphia.

APPENDIX

University of Nevada, Reno, Rock Mechanics Laboratory

PERMEABILITY TEST DATA SHEET

Sample Number (*SN*):	Permeameter: ☐ PVC ☐ Stainless steel
Sample length (L):	Sample Diameter (D):
System reference height (H):	Sample density (ρ_s):
Unit length volume (l) upper pipette (l_u): bottom pipette (l_b):	Brine density (ρ): Brine concentration (M):
Gas type:	Tested by:

Date (mm:dd:yy)	Time (hh:mm:ss)	Pressure Head (cm)		Applied pressure P (psi)	Temperature (°C)
		H_1	H_2		